25.—Jurassic Stratigraphy of the Geraldton District, Western Australia

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This paper is a detailed account of the stratigraphy, structure, and petrology of the Jurassic sediments of the Geraldton district. These sediments are almost horizontal and were deposited on an irregular, weathered surface of Precambrian gneisses and granulites. The Jurassic sediments are divided into seven formations, of which the lower six form two groups. They are, from the base up, the Greenough Sandstone and Moonyoonooka Sandstone (making up the Chapman Group), the Colalura Sandstone, Bringo Shale, Newmarracarra Limestone, and Kojarena Sandstone (making up the Champion Bay Group), and the Yarragadee Formation. The age of the Chapman Group has not been definitely established owing to lack of fossil evidence. It consists of continental fluviatile sandstones and is tentatively placed in the Lower Jurassic, though all or part of the group may be Upper Permian or Lower Triassic. The Champion Bay Group consists of marine sediments of Middle Jurassic age. One formation, the Newmarracarra Limestone, is very fossiliferous, and has been accurately dated as Middle Bajocian.

The flat-topped hills of the Geraldton district are usually capped by laterite, which is often overlain by sand. These hills are remnants of the well-dissected Victoria Plateau. The laterite in the district formed after uplift and dissection of the plateau. Both the Precambrian granitic rocks and the Jurassic sediments (especially the Newmarracarra Limestone) have undergone extensive alteration beneath the laterite.

The major structural feature of the area is the Geraldton Fault, which is known to have had a throw since the Jurassic of 750 to 800 feet, and a total throw of at least 1,500 feet. Minor faults, cutting both the Jurassic sediments and the Precambrian rocks, have also been noted in the area.

Contents

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Introduction

Location of Area

Geraldton is situated on the coast of Western Australia, about 230 miles north of Perth, the capital city. It is a port on Champion Bay, serving the surrounding agricultural and mining districts.

During this investigation an area of approximately 400 miles around Geraldton was examined in reconnaissance (see Plate 4), and a detailed survey was carried out on approximately 14 square miles in the vicinity of Bringo, a small railway station 19 miles from Geraldton on the line to Mullewa.

Purpose of Investigation

The marine Jurassic sediments of the Geraldton district have been known since the middle of the last century, and were until comparatively recently the only known exposure of marine Jurassic in Australia. Nevertheless no detailed geological investigation of the area has been undertaken previously, due largely to the lack of any economically important deposits associated with the sediments. The objects of the present survey were firstly to map a small area of the Jurassic sediments in detail, establishing the rock units present, collecting fossils, and carrying out a laboratory examination of the sediments; secondly to map a larger area in reconnaissance, measuring stratigraphic sections throughout, and obtaining information on the lateral extent of the rock units. The overlying lateritic deposits and underlying Precambrian metamorphic rocks were also studied.

This paper was originally submitted in March, 1953, as part of the requirements for the degree of Bachelor of Science with Honours at the University of Western Australia. Since then, part of the Geraldton area has been re-examined by Mr. S. P. Willmott and myself during the course of a regional geological survey of the Perth Basin on behalf of West Australian Petroleum Pty. Limited. Some alteration to the original manuscript has been necessary as a result of this additional work.

Methods of Study

The area around Bringo which was examined in detail (see Plate 5), was mapped using vertical aerial photographs, on a scale of four inches to the mile. In this area every outcrop was visited and examined. The reconnaissance survey (Plate 4) was carried out using the army topographical maps on a scale of one inch to the mile. For this survey all outcrops were not visited, but roads and important tracks in the area were covered by motorcycle, with visits to significant exposures. The regional map was completed in Perth using vertical air-photos loaned by the Army Survey Corps.

The Bringo railway cutting (Plate 6) was mapped on a section prepared from measurements supplied by the Engineer's Department, Western Australian Government Railways.

A petrological examination was carried out in the laboratory of samples collected mainly from the area mapped in detail. This analysis consisted of mechanical analysis, sphericity and roundness determinations, and mineralogical study of the disaggregated sediments, supplemented by thin section work. Chemical analyses were carried out on the phosphatic rocks to determine their content of P_2O_5.

Macro-fossils were identified from the literature and the ammonites were sent to the late Dr. W. J. Arkell.

The army one-mile grid system is used on the geological maps of the Geraldton and Bringo areas respectively (Plates 4 and 5). Localities mentioned in the text are referred to this grid. Taking Bringo as an example, the east-west reading is 75.9 and the north-south reading is 36.5, then the grid reference is given as (759365). In the same way the grid reference for "Moonyoonooka" homestead is obtained as (708325).

Historical Review

The Geraldton district was one of the earliest parts of Western Australia to be settled, and in the early 1850's several sheep stations were established in the area covered by this report. Such stations as "Newmarracarra," "Tibradden," "Ellendale," and "Sandspring" were soon flourishing in an area which proved to be among the richest pastoral districts in Australia. It is not surprising that the richly fossiliferous rocks of the area attracted the attention of these early settlers, and as a result several fossil collections were sent to England.

The first to record the Jurassic age of these fossils was Moore (1862), who examined specimens forwarded by a Mr. Clifton, and also those sent by F. T. Gregory to the Geological Society of London. Moore expressed the opinion that the fossils were referable to the Upper and Middle Lias of the English succession. Earlier, A. C. Gregory (1849), J. W. Gregory (1849), F. von Sommer (1849), and F. T. Gregory (1861) had written brief accounts of the geology of the district, but none had recognized the Jurassic age of the sediments.

The Reverend W. B. Clarke (1867) published a paper on fossils he had been sent from the Moresby Range, near Geraldton. His conclusion was that "Taking the general aspect of these fossils, and the occurrence of such forms as *Avicula Munsteri*, *Ostrea Marshi*, and *Ammonites Moorei*, it is almost certain that the nearest representative of the formation is the Inferior Oolite." This conclusion is held to the present day, the Newmarracarra Limestone being considered to be of Bajocian ("Inferior Oolite") age, though it has been further narrowed down to the Middle Bajocian.

Further palaeontological papers on fossils from the Geraldton area were published by Neumayr (1885), Crick (1894), Etheridge (1901, 1910), and Chapman (1904, *a* and *b*).

The first geologist to map the Geraldton district at all thoroughly was W. D. Campbell (1907), who published a geological map of the Greenough River district, with accompanying notes. This map shows the broad distribution of the Jurassic sediments, Precambrian rocks, and laterite, but the notes give little information on the stratigraphy of the area.

Further work on the area by Campbell (1910) was published as part of his outstanding contribution to the geology of Western Australia—"The Irwin River Coalfield and the adjacent districts from Arrino to Northampton." This report embraced an area of about 2,000 square miles, and included the area covered by the present survey. However, Campbell was mainly concerned with the Permian sediments of the Irwin River district, and his report contains no detailed information on the stratigraphy of the Jurassic sediments.

The next palaeontological paper was by F. W. Whitehouse (1924), who examined fossils collected by Professor W. G. Woolnough from a railway well near Bringo. He named several new species, and on evidence supplied by ammonites, suggested a Middle Bajocian age for the fauna. This dating was confirmed by Spath (1939), who described a small collection of ammonites from the Geraldton area. He considered that they were referable to either the Sauzei Zone or the Sowerbyi Zone (Middle Bajocian) of the European succession.

The geological survey of the Irwin River and Eradu coal basins (Permian) by Johnson, de la Hunty, and Gleeson (1954) overlaps the present reconnaissance in the vicinity of Wicherina. However their paper gives little information on the Jurassic sediments.

The field work for the present investigation was undertaken in December 1951, January, February, June, August and November 1952, and March 1953, a total of 17 weeks being spent in the field. The laboratory work was done during the academic year of 1952.

Since the present paper was submitted as an Honours thesis in 1953 two papers have been published dealing with the Jurassic sediments of the Geraldton area. The first (Arkell and Playford 1954), deals primarily with the ammonities of the Newmarracarra Limestone, which are described in that section of the paper written by Arkell. He considers the fauna to be Middle Bajocian in age, and to correlate, at least in part, with the Sowerbyi Zone of the European succession. The Sauzei and Humphriesianum Zones of the Middle Bajocian may also be present. The other section of the paper, by myself, summarizes the stratigraphy of the Jurassic sediments. In "The stratigraphy of Western Australia" by McWhae, Playford, Lindner, Glenister, and Balme (1958), the latest information on the Jurassic sediments of the Geraldton area is given in summary form.

Acknowledgments

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Physiography

General

The Geraldton district is situated in the northern part of the Perth Basin. It falls within the Greenough Natural Region of Clarke (1926), the South-West Physiographic Division of Jutson (1934), and the Greenough Block Subregion of the Swan Coastal Belt (Physiographic Region) of Gentilli and Fairbridge (1951).

The country to the east of Geraldton consists of the remnants of a plateau dissected by the Greenough and Chapman Rivers, leaving flat-topped hills of Jurassic sediments, often capped by laterite, and underlain by Precambrian granitic rocks. The western margin of the dissected plateau is marked by the Geraldton Fault Scarp (Jutson 1914). This scarp is deeply dissected and has retreated several miles. It is fronted by a coastal plain, 3 to 10 miles wide, which slopes gently to the sea.

In those areas where the rivers have cut through the sand-covered plateau, there are rich pastoral properties supporting large numbers of sheep. Cereal crops are also grown, being most successful in the drier years, while there are numerous market gardens on the coastal plain.

The climate of the area is characterized by an annual rainfall of 15 to 20 inches, nearly all of this falling in the winter months. Summer temperatures are high, with the maximum often over 100°F.

The natural vegetation has been largely removed in the valleys of the Chapman and Greenough Rivers, but on the granitic and Jurassic areas it apparently originally consisted predominantly of "Jam" (*Acacia acuminata*), "York Gum" (*Eucalyptus foecunda*, var. *loxopheba*), "Needle Bush" (*Hakea recurvata*), and "Sheoak" (*Casuarina*). There is a marked change of vegetation on the sand-plain, which supports a low scrub, including stunted species of *Acacia* and *Banksia*, with occasional "Christmas Trees" (*Nuytsia floribunda*).

River Systems

The Geraldton district is drained by two main rivers, the Greenough and the Chapman. Another so-called river, the Buller, is in reality little more than a creek. Like most Western Australian rivers they are intermittent, only flowing after heavy rain.

The Greenough River rises 130 miles north-east of Geraldton, and only the lower part of its course lies within the area examined. In this part of its course it receives two main tributaries, Wicherina Brook and Colalura Brook, the latter draining the area surveyed in detail.

Upstream from the road crossing near Ellendale (890232) the Greenough River flows through Jurassic sediments in a series of large ingrown meanders, with undercutting along high cliffs and prominent slip-off slopes. These ingrown meanders continue upstream in the Eradu district, and as suggested by Johnson, de la Hunty and Gleeson (1951), they indicate a rejuvenation of a river which had reached the "old age" stage of development. This rejuvenation must have occurred following uplift of the plateau in late Tertiary times. The Murchison River, 80 miles to the north, shows even clearer evidence of rejuvenation. West of the Greenough Block (Precambrian granitic rocks) it flows in a deep, narrow gorge with well-developed incised meanders.

For 10 miles south of its mouth the Greenough River flows over a rich flood-plain known as the Greenough Flats. These flats are divided into two parts by a low sand-covered ridge of Coastal Limestone, which is parallel to the coast. (This ridge is about three miles inland and represents consolidated coastal sand dunes of Pleistocene age.) The river flows between the ridge and the present dunes, following them north for $10\frac{1}{2}$ miles before breaking through to enter the sea. This northerly deflection of the river is due to the strong prevailing south-south-west winds which sweep the coast. The picturesque trees along the Greenough Flats, bent over almost parallel to the ground, testify to the constancy and strength of these winds. Sand carried by the resulting northerly long-shore drift, combined with the slow migration of sand dunes, has caused the mouth of the river to migrate northwards, as its old mouth is progressively filled in.

As first pointed out by Jutson (1914) Rudds Gully probably represents an abandoned course of the Greenough. This gully breaks through the Pleistocene dune limestones and is up to 90 feet deep, but today it carries only a small creek which seldom flows. It seems very likely that during the Pleistocene the river emptied into the sea at Rudds Gully, flowing north behind the Pleistocene dunes just as today it flows behind the present dunes.

The Chapman is much smaller than the Greenough. It divides into two branches near "Narra Tarra", and these are known as the Upper Chapman and East Chapman branches. The Upper Chapman rises 35 miles north of Geraldton, and the East Chapman rises near Northern Gully.

Victoria Plateau

The Victoria Plateau was named by Johnson *et al.* (1951), who defined it as the dissected plateau bounded on the east by the Darling Fault, and on the west by the Geraldton Fault and the high sea cliffs north of Geraldton.

In the Geraldton district the Victoria Plateau has been deeply dissected by the Greenough and Chapman Rivers, leaving large remnants such as the Moresby Range. The surface of the plateau is covered by sand overlying laterite, generally at shallow depth. The laterite itself outcrops along the edges of the plateau, or in those places where the sand has been removed by erosion.

The surface of the plateau shows only minor undulations, and averages about 800 feet above sea-level.

Hills

The most conspicuous hills of the Geraldton district are flat-topped (buttes and mesas), their outline being due to the resistant nature of the laterite cap overlying soft Jurassic sediments. The laterite cap is generally flat, though in some cases it shows a sloping surface.

The Moresby Range is made up of a series of parallel, elongated mesas and buttes, trending north-north-west, and standing about 200 feet above the surrounding plain. Laterite, sometimes overlain by sand, caps most of the range, though in places this has been removed by erosion, and Jurassic sediments outcrop at the top. The western edge of the range is the retreated scarp of the Geraldton Fault, and the eastern margin is due to dissection by the Chapman River, which parallels the range.

Those hills of Jurassic sediments which are not capped by laterite have a rounded outline, and examples of these are found typically in the area mapped in detail.

Springs

Springs are common throughout the area examined. Some issue at the unconformity between the Jurassic sediments and the Precambrian rocks, and these are generally brackish or salt. Others, either fresh or brackish, are found in the sediments at the contact between sandstone and shale, or limestone and shale. The latter type has a widespread development east of Bringo, where limestone overlies black shale.

Much of the rain falling on the sand-plain sinks in, there being very little run-off, and the water often reappears as fresh-water springs beneath the underlying laterite.

General Geology

Precambrian

Precambrian metasediments outcrop over a large proportion of the area, though exposures are generally poor. These rocks have undergone high-grade regional metamorphism, and consist of granitic gneisses and granulites, which are characteristically garnetiferous.

The petrology of the Precambrian metasediments has not been intensively studied, though thin-sections of some of the most typical rock types have been examined.

The gneisses are the most abundant of the Precambrian rocks present in the area. They are usually medium-grained, uniformly banded, and almost invariably carry garnet. Sillimanite is sometimes present, usually as a minor accessory. Some of the gneisses also contain cordierite. Typical examples of the gneisses are specimen No. 34797 (University of W.A. Geology Dept. registered number), which is a quartz-orthoclase-andesine-garnet gneiss, and specimen No. 34798, which is a quartz-microcline-oligoclase-garnet-cordierite gneiss.

Several types of granulite have been noted in the area, but they have not all been examined microscopically. Most have a composition similar to that of the granitic gneisses, and at several localities the granulites and gneisses grade into one another. Other types are interbedded with the gneisses and include charnockitic granulites, hornblende granulites, and garnetiferous quartzites.

The metasediments are cut by pegmatites, and at several localities by quartz veins, which are probably associated with pegmatites.

At a few places in the area the gneisses and granulites are intruded by dolerite dykes. The one crossing the area mapped in detail is at least 2½ miles long, stretching from a quarry at (746361) to (728325), near Spion Kop. The strike of 26° closely parallels that of the dyke swarm of the Northampton district, 30 miles to the north, where the dolerite dykes have introduced lead, copper, and zinc into the gneisses.

Lineation is seldom pronounced in the gneisses, but readings have been taken at three widely separated localities (635426, 774356, 811215). The strike of the lineation is rather constant, averaging 335°, while the angle of plunge varies from 12° south to 70° north. This north-north-west tectonic trend is usual in the West Coast Province of Prider (1952).

Throughout the area the foliation of the gneisses varies little from a northerly strike and easterly dip, and they are probably isoclinally folded.

The contact between the Precambrian rocks and the Jurassic sediments is very irregular, and east of the Geraldton Fault the elevation of the unconformity above sea-level varies from about 250 feet near "Narra Tarra" and "White Peak" to 717 feet at Mt. Davis.

Although the Precambrian basement rises gradually from west to east, this rise is not uniform. There are irregularities in the surface of the unconformity, which existed as hills and valleys at the time when the Jurassic sediments were deposited. The basal formations of the Jurassic are found to pinch out against these buried hills, so that the lower the elevation of the unconformity, the greater is the thickness of the sediments.

The metasediments beneath the unconformity are frequently deeply weathered, the felspars being completely kaolinized to depths of 100 feet or more. This is particularly well seen in various small railway cuttings near Bringo. However most of this remarkable depth of weathering is believed to be associated with lateritization, and was not present in Jurassic times. Similar deep weathering of metasedimentary rocks beneath laterite is known in many other places in Western Australia. Nevertheless a certain amount of weathering of the Precambrian rocks is believed to have occurred in Jurassic times. The basal formation of the Jurassic succession, the Greenough Sandstone, is made up of highly weather granitic material, and is believed to be locally derived.

Lower Silurian (?)

There are a few exposures of the Tumblagooda Sandstone in the area west of Wicherina. These are the southernmost known outcrops of this formation, which is best known along the Murchison River on each side of the Greenough Block. The Tumblagooda Sandstone is probably of Lower Silurian age.

The exposures of Tumblagooda Sandstone near Wicherina consist of fine- to very coarse-grained, grey to yellow, well-sorted sandstone, which is partly silicified. The sandstone is crudely to well-bedded and sometimes shows cross-bedding. Scattered well-rounded pebbles and cobbles of quartz and quartzite are a feature of these exposures of the formation. At the large water tank 2½ miles west-south-west of Wicherina Dam, many pebbles and cobbles have weathered out of the formation and are scattered over the surface.

The relationships between the Tumblagooda Sandstone and the over-lying Jurassic sediments cannot be seen in the exposures near Wicherina. However 5½ miles north of Northern Gully (off the map) the Lower Jurassic Chapman Group can be seen resting unconformably on the Tumblagooda Sandstone. The Tumblagooda Sandstone overlies the Precambrian granitic rocks unconformably. Only one satisfactory dip could be measured in the exposures of the formation near Wicherina, at (879400). There the unit is crudely bedded and cross-bedded, but it appears to strike 140°, and dip 15° west.

The only fossils known from the Tumblagooda Sandstone are invertebrate tracks, which indicate an early Palaeozoic age. However there is evidence to suggest that the formation is at least in part of Lower Silurian age, though it may extend down into the Ordovician. This dating is indicated by the fact that the formation appears to underlie conformably the Middle Silurian Dirk Hartog Limestone in the Dirk Hartog 17B bore (McWhae *et al.* 1958).

The exposures of the Tumblagooda Sandstone near Wicherina are only a few feet thick. However on the Murchison River it appears that the unit is at least 6,000 feet, and probably exceeds 10,000 feet in thickness. It is probably present at depth throughout most of the Perth Basin and is believed to be a continental fluviatile deposit laid down following the first major period of movement along the Darling Fault, in Lower Silurian or late Ordovician times.

Johnson *et al.* (1954) correlated the exposures of Tumblagooda Sandstone near Wicherina with the Enokurra Sandstone of the Yandanooka Group, which is exposed 60 miles to the south-south-east. However the exposures near Wicherina have now been shown to be essentially continuous with those of Tumblagooda Sandstone extending down from the Murchison River, and the correlation with this formation cannot be seriously doubted. The lithological similarity with the Enokurra Sandstone is quite strong, but this is not sufficient to establish correlation. Indeed it is now believed that the Yandanooka Group is distinctly older than the Tumblagooda Sandstone.

Upper Permian or Lower Triassic

Sediments of Upper Permian or Lower Triassic age were first discovered in 1956 in cores from the Geraldton Racecourse Bore (569307). This bore was drilled with Calyx equipment in 1896-98 and some of the cores were preserved by the Geological Survey of Western Australia. A core from 1,470 feet in this bore was found to contain the uppermost Permian or lowermost Triassic ammonoid *Xenaspis*.

The formation was named the Kockatea Shale by Playford and Willmott in McWhae *et al.* (1958). It consists of partly calcareous, light grey shale, grading into siltstone, with subordinate interbedded medium- to coarse-grained sandstone.

In the Geraldton area the Kockatea Shale is known with certainty only from the Geraldton Racecourse, Municipal, and Station Yard bores. In the Municipal Bore the unit is 1,091 feet thick and overlies Precambrian gneiss, while in the Racecourse Bore it is 1,131 feet thick, without having reached the base of the formation. In both bores the Kockatea Shale is overlain by Jurassic sediments.

Dr. Glenister, who has examined the ammoniod *Xenaspis* from the Racecourse bore, favours a Tatarian (uppermost Permian) dating for the formation (McWhae *et al.* 1958). On the other hand Mr. B. E. Balme, from a study of the spore, pollen and microplankton assemblages, believes that it is more likely to be lowermost Triassic, though he does not rule out the Tatarian dating.

Although the Kockatea Shale is not definitely known to outcrop in the Geraldton area, it could conceivably be present. The Greenough Sandstone, which is tentatively dated as Lower Jurassic, shows lithological similarity to parts of the Kockatea Shale, and they may be partly equivalent. The only certain exposures of the Kockatea Shale in the Perth Basin are found near the junction of Kockatea Gully with the Greenough River.

Jurassic

In the Geraldton District Jurassic sediments are known to extend from the northern end of the Moresby Range as far south as Mt. Hill, and both marine and continental deposits are found in this area. The marine transgression is known to have extended inland at least as far as Eradu, on the Greenough River.

Although a Jurassic age is proved for the marine sediments, one formation being accurately dated as Middle Bajocian, there is no direct proof as to the age of the continental deposits, though they are tentatively placed in the Lower Jurassic.

In summary the sequence, from top to bottom, is as follows:

Yarragadee Formation.—Alternating sandstone and micaceous siltstone, with beds of claystone, shale, and conglomerate.

Thickness: 51½ feet (plus).

Champion Bay Group:

Marine sandstone, shale, and limestone making up the following formations:

Kojarena Sandstone.—Brown ferruginous sandstone, partly fossiliferous, with some claystone and shale near the top.

Thickness: 33 feet.

Newmarracarra Limestone.—Yellow to grey, massive, richly fossiliferous limestone. The limestone is subject to irregular alteration, and may be replaced by hematite, or leached of calcium carbonate, leaving a residue of its clastic impurities.

Thickness: 16 to 38 feet.

Bringo Shale.—Black shale, with thin yellow phosphatic beds. Phosphatic nodules often found at the top. Dwarf pelecypods occur at several horizons.

Thickness: 0 to 8 feet.

Colalura Sandstone.—Predominantly brown to black ferruginous sandstone, rarely grading into yellow sandy claystone. Abundant fossil wood is characteristic, and small oval nodules are frequently found. Both nodules and fossil wood are sometimes phosphatic, but are usually replaced by limonite. Marine fossils rarely present.

Thickness: 0 to 28 feet.

Chapman Group:

Continental sandstone and arkose, with subordinate shale, siltstone, and claystone, making up the following formations:

Moonyoonooka Sandstone.— Predominantly yellow fine-grained felspathic sandstone and arkose, with subordinate shale, siltstone, and conglomerate. Well-bedded, with cross-bedding and current ripple-mark common. Ferruginous concretions are characteristic, fossil wood is quite abundant, and fossil leaves are very rare.

Thickness: 0 to 120 feet.

Greenough Sandstone.—Mottled red, white, yellow, and purple argillaceous sandstone, poorly sorted, with subordinate shale, siltstone, claystone, and conglomerate. Poorly bedded, and containing rare fossil wood.

Thickness: 0 to 280 feet.

In the area examined, the total exposed thickness of the Jurassic and questionable Jurassic sediments probably does not exceed 550 feet. No single section exposes as much as this. The thickest section measured is at Wokatherra Hill at the northern end of the Moresby Range, where about 430 feet of sediments are exposed, the upper portion of the Champion Bay Group and the Yarragadee Formation being missing. The upper section is exposed in the Bringo railway cutting, but there the Precambrian basement is so high that nearly all the Chapman Group is excluded, and the total section is only 115 feet thick.

Jurassic and associated lowermost Cretaceous sediments are widespread in the Perth Basin, and may exceed 8,000 feet in thickness. They are predominantly continental sediments, the only marine Jurassic outside the Geraldton area being found in the drainage area of the Hill River, 100 miles south of Geraldton.

Laterite and Sand Plain

A considerable part of the area is covered by laterite, which is often overlain by sand. These deposits, which have a widespread development throughout Western Australia, are generally considered to be fossil soil horizons, formed during a more pluvial period, probably in late Tertiary times. Laterite may have been deposited under a humid climate of seasonal rainfall as an illuvial soil horizon zone of fluctuation of the water table. The sand-plain which is frequently found overlying laterite is believed to be the fossil eluvial horizon.

The laterite is up to 20 feet thick, and outcrops as large massive slabs around the sides of hills, giving rise to "breakaways." The laterite shows an irregular cellular structure, in some places partly concretionary. The weathered surface is yellowish brown in colour, while freshly broken surfaces are mottled in various shades of brown, yellow, and red.

The laterite consists of hydrous and anhydrous oxides of iron and aluminium, together with quartz and minor amounts of other insoluble minerals. The quartz present is usually of sand grade, though some large, rounded pebbles are occasionally found.

Overlying the laterite, wherever erosion is not too severe, deposits of quartz sand are found, which are light grey to white on the surface, and yellow at depth. This sand, which is probably no more than 20 feet thick anywhere in the area, is believed to be essentially *in situ*, though it may have undergone some redistribution, filling small depressions in the surface of the laterite.

Many of the hills in the Geraldton district which are capped by laterite are flat-topped, though the surface of the laterite is by no means invariably horizontal. It may show dips of anything up to 10°, as at Mt. Hill. Sloping laterite is also well seen on the three adjacent hills Sheehans Hill, Wizard Peak, and Browns Table. It is also found that, in general, the laterite slopes towards the present river valleys, indicating that the general features of the present drainage system were already established at the time when the laterite was forming.

The surface of the laterite in the Geraldton district shows considerable variations in elevation. To the east, where there are large remnants of the old plateau, the laterite (or the overlying sand) is usually more than 800 feet above sea-level, reaching 863 feet near Kojarena, and 821 feet at Mt. Julia. However, laterite (*in situ*) at "Amuri Park" is 350 feet above sea-level, while in the gravel pit at (644317) it is only 210 feet above sea-level. It is clear that laterite in the Geraldton area did not form on a low-lying peneplain of the type postulated by Woolnough (1918). It formed on a land surface already uplifted and eroded, the drainage system found today having been already established during the period of laterization. This is discussed in more detail by Playford (1954).

The effects of laterization in the Geraldton area are found to extend to considerable depths below the laterite itself. These effects are most apparent with the Precambrian granitic rocks and the Newmarracarra Limestone. The granitic rocks are found to be completely kaolinized to depths of more than 100 feet below the laterite. The upper part of this weathered zone is typically mottled white and various shades of red and brown, and is commonly known as the mottled zone. The lower part is simply white due to kaolin, and is known as the pallid zone.

Many of the structures and textures of the original rock are preserved in its kaolinized equivalent, particularly in the pallid zone. Thus gneissic structure is frequently clearly visible, and in the Bringo cutting, the original ophitic texture can still be detected in a thin dolerite dyke, despite the fact that the felspars are completely kaolinized.

The Newmarracarra Limestone is completely altered to depths of 80 to 100 feet beneath laterite. It is either replaced by hematite or simply leached of its calcium carbonate, leaving a residue of the clastic impurities. In those places where the rock is clearly altered limestone it has been mapped as Newmarracarra Limestone, but wherever there is uncertainty, or it approaches normal laterite in appearance, it has been mapped as laterite.

Alteration of the Newmarracarra Limestone by lateritization has been discussed fully in papers by Playford (1954) and Arkell and Playford (1954), and will only be summarized here.

Newmarracarra Limestone replaced by hematite is free of calcium carbonate, and varies in colour from deep red to almost black. Moore (1870) gave analyses of two blocks of the hematite and they contained 49% and 56% of metallic iron. The hematite was probably derived by leaching of the overlying ferruginous Kojarena Sandstone.

Fossils are often very well-preserved in the hematite rock, either as moulds or as replacements. However, in some areas, e.g. in parts of the Bringo cutting, the hematite rock shows a concretionary structure, and fossils are wholly or partly destroyed.

A leached zone is usually present between the hematite rock and the solid limestone. It has formed by removal of calcium carbonate, followed by compaction of the remaining insoluble clastic impurities. Its composition is usually that of sandy, silty claystone, and it is generally yellow in colour. This zone contains few fossils, those which are present being internal moulds of ammonites and pelecypods. The material of these moulds was apparently low in calcium carbonate, so that they were not destroyed during leaching.

The best exposure of the leached zone and associated hematite rock is in the Bringo cutting. There it can be seen that they are not sharply separated, one grading irregularly into the other.

In the field the relationship between limestone outcrop and elevation of laterite is quite apparent. Wherever the undulating surface of the laterite is closer than about 90 feet to the base of the Newmarracarra Limestone, the limestone is completely leached. Exposures of unaltered limestone are only found where the laterite is more than about 90 feet above the base of the formation.

The other sediments also show the effects of lateritization, though not so clearly as the Newmarracarra Limestone. The mottled zone is frequently visible close to laterite in all formations, and beneath this there may be a bleached zone, though this is seldom exposed, as removal of the iron oxide cement of many of the sand stones makes them friable.

A feature which is believed to be associated with laterization is the occasional silicification of sediments. Near Mt. Hill, about ¾-mile west of the summit, the sandstones of the Chapman Group are silicified to a depth of 50 feet or more. These sandstones are at an unknown depth below the original laterite surface, which is known to have been very irregular here, for laterite occurs on the north flank of Mt. Hill, more than 100 feet below the summit, yet it does not occur on the summit itself.

Quaternary Superficial Deposits

In addition to laterite and sand-plain, other superficial deposits have a widespread distribution in the area, but have not been studied in any detail. These deposits include surface travertine, Coastal Limestone, Recent sand dunes, and alluvium. All are of Quaternary age.

The deposits of travertine are found in small patches throughout the area, where they are exposed to erosion, giving rise to surfaces covered by fragments of the white, lime-rich rock.

Alluvial deposits have been spread over most of the coastal plain, and inland around the margins of the Victoria Plateau. Alluvial sand deposits are commonly found around remnants of the plateau, the sand having been washed from the tops of the hills where it previously covered laterite.

Alluvial deposits are exposed in several parts of the Bringo cutting in old valleys cutting through the Kojarena Sandstone and Yarragadee Formation.

Jurassic Stratigraphy

Chapman Group

The name Chapman Group was introduced by Playford, in Arkell and Playford (1954), for the continental sediments lying between the unconformity with the Precambrian rocks and the disconformity with the overlying Champion Bay Group. It was named after the Chapman River. The group was originally considered to be made up of two formations, the Greenough Sandstone and the Moonyoonooka Sandstone, but was expanded by Johnstone and Playford (in McWhae *et al.* 1958) to include the Minchin Siltstone, which lies at the base of the group in the Northampton-Hutt River area. As this formation is not exposed in the Geraldton area, it will not be discussed further in this paper.

The age of the Chapman Group is uncertain owing to the lack of satisfactory fossils for dating. It is not even certain that the formations of the group form a continuous sequence.

However the three formations are tentatively regarded as being of Lower Jurassic age, keeping in mind that one or more could be Lower Triassic or Upper Permian.

(i) *Greenough Sandstone*

Definition.—The name Greenough Sandstone was proposed by Playford, in Arkell and Playford (1954), for the unit of sandstone with minor shale, claystone, and siltstone, lying between the granitic rocks and the Moonyoonooka Sandstone in the area east of Geraldton. The name was taken from the Greenough River, the largest river flowing through the area.

The type section of the Greenough Sandstone is on "Moonyoonooka" property, at 28° 47' 4" S., 114° 48' 3" E. (722319). The following is a description of this section.

Moonyoonooka Sandstone. Comformably overlying—

Greenough Sandstone (90')

	Thickness feet
(6) Sandstone, clayey, mottled grey, white, yellow, red, and purple; in places grades into sandy claystone; top marked by a 3" bed of hard, ferruginous claystone with purplish bands	45
(5) Conglomerate, intraformational, mottled grey, yellow, and red; contains angular and rounded fragments of clay in a matrix of course sand	5
(4) Claystone, mottled red and white, massive	1½
(3) Sandstone, clayey, yellow, mottled red and white; contains scattered fragments of angular and rounded claystone; fills scour channel in underlying shale, conglomeratic at base; bleached and hardened along joints	11
(2) Shale, white to yellowish, mottled red, yellow, and purple; massive claystone at base, but otherwise shaly; lenses of sandstone found in the uppermost two feet; hard ferruginous beds up to ½" thick common throughout	23
(1) Sandstone, conglomeratic, felspathic, brown to reddish brown, ferruginous, contains poorly rounded quartz pebbles up to 6" in diameter; a few felspar pebbles, and occasional boulders of weathered gneiss at the base	5

unconformably overlying Archaean gneiss (weathered).

Lithology.—The Greenough Sandstone is typically a mottled red and white argillaceous sandstone, which is medium to coarse-grained, and is very poorly sorted and poorly bedded. Lenses of siltstone, claystone, and shale are present in the formation, with occasional quartz pebble conglomerates. Lenses of intraformational conglomerate occur rather commonly throughout the section, and cut-and-fill structure, giving rise to local unconformities, has been noted at several localities. Cross-bedding is rarely developed in the sandstones, which are usually massive, with no bedding visible. Sand grains show little or no rounding, but quartz pebbles are sometimes well-rounded.

It is often difficult to recognize the exact position of the unconformity, as the weathered Precambrian rocks frequently appear to grade up into the Greenough Sandstone. This is because the sandstone seems to be merely reworked, highly weathered granitic material, and it is frequently only the relic gneissic structure in the weathered Precambrian, or the presence of a few quartz pebbles in the sediment, which serves to distinguish them.

One of the most distinctive features of the formation is its mottled colouring, red and white being most common, but shades of grey, yellow, blue, purple, and brown are also found. Black or dark grey sediments have not been found in this formation. The origin of this mottling is not definitely known, but most of it is certainly secondary, as it transgresses the bedding. Along joints it is often found that the sandstone is both irregularly bleached and hardened. However much of the mottling does not seem to be connected with joint planes, though it is almost certainly secondary, and due to circulating ground waters. Since the sandstones are mottled even when hundreds of feet below laterite, there appears to be no connection with the mottled zone which is found immediately beneath laterite.

The mineralogy of the formation is very monotonous. Quartz and clay minerals, probably mainly kaolinite, together with a little muscovite, are usually the only "light" minerals. Felspar is rare, only being found near the base of the formation. The heavy mineral suite is also very restricted. Zircon is by far the most abundant of the non-opaque minerals, with minor amounts of anatase, monazite, tourmaline, and rutile. The extreme rarity of metamorphic minerals (kyanite, staurolite, and garnet) is very noticeable, as they are much more abundant in the other formations.

Stratigraphic relationships.—In the Geraldton district the Greenough Sandstone rests unconformably on the weathered, irregular surface of the Precambrian rocks, and is overlain conformably by the Moonyoonooka Sandstone. In the Hutt River-Bowes River area, near Northampton, the Greenough Sandstone rests with a slight disconformity on the Minchin Siltstone.

The contact between the Greenough Sandstone and the Moonyoonooka Sandstone is exposed at the type section, where it is clearly defined, but this contact has seldom been observed elsewhere owing to the poorness of outcrop. In this section the mottled argillaceous sandstone and sandy claystone of the Greenough Sandstone are overlain conformably by a black shale containing numerous lenses of grey sandstone and conglomeratic sandstone. As black and dark grey sediments are not known in the Greenough Sandstone, this shale is assigned to the next formation, the Moonyoonooka Sandstone, which in some areas contains significant amounts of dark shale.

Distribution and thickness.—The distribution of the Greenough Sandstone is limited by the elevation of the Precambrian basement, and if this rises higher than about 530 feet above sea-level, the formation pinches out. Since the basement rises gradually, though irregularly, from west to east, the formation thickens to the west.

At Wokatherra Hill, the most northerly and most westerly section studied, the greatest thickness of the Greenough Sandstone, 280 feet, has been measured. The formation has thinned to 60 feet at Appa Hill, and pinches out near Grant Siding. Outside the area examined the formation is known to reach a maximum thickness of 310 feet, at Kings Table Hill.

The formation is absent over a large part of the area examined, for around Bringo, "Tibradden," "Sandspring," and "Minnenooka," the Precambrian is sufficiently high to exclude it.

Exposures of the Greenough Sandstone are in general poor, for the sediments are usually weakly lithified. In the area mapped in detail the most typical outcrops of the Greenough Sandstone occur on two small hills at (69834), though the type section is the only continuous section exposed. Other good outcrops of the formation are found on "White Peak" property, along the western flank of the Moresby Range, and in a few railway cuttings near Grant Siding.

Fossils and age.—The only fossils which have been found in the Greenough Sandstone are rare, poorly preserved fragments of wood.

The age of the formation has not been definitely established owing to the lack of fossil evidence, but it is tentatively placed in the Jurassic. However it may be Lower Triassic or Upper Permian in age.

Environment of Deposition.—The Greenough Sandstone is considered to be a fluviatile sediment deposited around elevated areas in the Precambrian rocks. Most of the sediment is probably locally derived, having undergone little transportation.

A continental, fluviatile origin of the sediments is indicated by the following features:—

(a) Marine fossils are absent, the only fossils which have been found being fragments of wood.

(b) Individual strata are laterally impersistent, a characteristic feature of fluviatile deposits.

(c) Typical colours found in the formation are red, yellow and brown. The colouring matter is ferric oxide, which is normally reduced under marine, paludal, or lacustrine environments, and is best preserved under non-reducing fluviatile environment.

(d) Subaerial exposure of the sediments is indicated by the prevalence of intraformational conglomerates and breccias. They indicated hardening and cracking of clays due to exposure to the air, followed by scouring of flood-waters, incorporating the hardened blocks in the succeeding sediment. Local unconformities are often associated with the intraformational conglomerates, and these are known to be quite typical of fluviatile deposits.

The sediment making up the Greenough Sandstone is believed to be largely locally derived from the nearby granitic hills. It fills valleys in the irregular surface of the Precambrian rocks. The sediment is almost unsorted, having a kaolinitic cement, and closely resembles the weathered granitic rocks both in composition and appearance. Rounding of sand grains and the bedding are always poor, confirming that the sediment has undergone little transportation.

Economic Aspects.—The Greenough Sandstone has been used to a limited extent as a building stone, and as such it is rather well-suited. The mottled colouring is attractive, and as it is never strongly consolidated, it is easy to work.

Small quarries have been opened at "White Peak" and "Moonyoonooka" Stations for the purpose of extracting this stone.

(ii) *Moonyoonooka Sandstone*

Definition.—The name Moonyoonooka Sandstone was introduced by Playford, in Arkell and Playford (1954), for the continental sediments, predominantly felspathic sandstones and arkoses, between the Greenough Sandstone, or the Precambrian rocks, and the overlying marine Colalura Sandstone. The name is taken from "Moonyoonooka" Station, which embraces a large part of the area mapped in detail (Plate 5). Moonyoonooka is also the name of a small railway station on the Geraldton-Mullewa line.

The type section of the formation is on "Moonyoonooka" Station and overlies the type section of the Greenough Sandstone. It commences in a creek bed at 28° 47′ 18″ S., 114° 47′ 36″ E. (714315), and continues up a hill to (714313). The following is a description of this section:—

Colalura Sandstone. Disconformably overlying—

Moonyoonooka Sandstone (103′)

	Thickness Feet.
(6) Arkose and felspathic sandstone, very fine- to medium-grained, partly silty, chiefly yellow, occasionally white and grey; contains some thin interbedded shales and siltstones; well-sorted, and usually well-bedded; shows cross-bedding, current ripple-mark, and occasional mud-cracks; some thin intraformational conglomerates are present; ferruginous concretions are common, barite concretions rare; fossil wood common in the centre of ferruginous concretions; one fossil leaf found	66
(5) Sandstone, medium-grained, brown ferruginous, massive; outcropping prominently	½
(4) Interbedded shales and fine-grained, cross-bedded felspathic sandstone; variegated yellow, grey, and white; some beds have incrustations of water-soluble salts	11
(3) Shale, black, carbonaceous, containing indeterminable plant fragments	5
(2) Sandstone, conglomeratic, brown, ferruginous, massive, lenticular, outcropping prominently, with well-rounded quartz pebbles; contains rare fossil wood	1
(1) Shale, black, carbonaceous, with lenses of brown sandstone, sometimes felspathic, conglomeratic, and containing rare fossil wood; sandstone lenses most abundant near the base, where they are several feet long, and on the average 3 in. thick	19

conformably overlying Greenough Sandstone.

Lithology.—The Moonyoonooka Sandstone consists for the most part of poorly consolidated felspathic sandstones and arkoses, which are predominantly yellow, but also white, grey, red, and brown. These sandstones are well-bedded, often very thin-bedded, and both cross-bedding and current ripple-mark are commonly found. In the area mapped in detail these indicate a current direction, which though variable, is predominantly from the south-east.

The sandstones are usually fine- to very fine-grained, and contain lenses of shale, siltstone, coarse sandstone, and conglomerate, which are dove-tailed together, conglomerate sometimes cutting through shale. The lenticular nature of these beds is very noticeable. The shales are usually white, grey, or black in colour, while the coarse sandstones and conglomerates are usually brown. Intraformational conglomerates are sometimes found, together with rare mud-cracks.

The sand grains for the most part show little rounding, though an occasional rounded grain is found, and in conglomerates the quartz pebbles and granules may be well-rounded.

Small ferruginous concretions are rather characteristic of the formation. These vary considerably in shape, but the most typical are subspherical, and from one to six inches in diameter. The outer surface is usually yellow in colour, but may also be brown or dark red. The centres of the concretions usually consist of yellow, grey, or green unconsolidated powder, surrounded by a hard limonitic shell. They have apparently formed by the decomposition of pyrite or marcasite. Some contain a piece of limonitized fossil wood, which was once probably pyritic or marcasitic.

A few barite concretions have been found weathered out of the formation, both in the type section, and at (723300). It was not possible to fix accurately the horizon from which they were derived.

The Moonyoonooka Sandstone shows a variable assemblage of minerals, which is in marked contrast to the Greenough Sandstone with its monotonous suite. The "light" minerals consist of quartz, felspar, and muscovite. Felspar is usually present in sufficient quantities to designate the sandstones as felspathic, and frequently there is sufficient to call them arkoses. The felspar, which is usually rather fresh, consists almost entirely of microcline and orthoclase, though odd grains of albite and oligoclase have been noted. Altogether 27 samples, collected over a wide area from this formation, have been examined microscopically to determine their felspar content. Of these, 13 were felspathic sandstones (10 to 24% felspar), 11 were arkoses (25% or more felspar), and three were quartzose sandstones (less than 10% felspar). A noticeable feature of this examination was that of six samples from the type section, five were arkoses, and the other was a felspathic sandstone.

Muscovite flakes are frequently present in the sandstones, in quantities up to 5%. The flakes occur along the bedding planes, so that the sandstones split readily along these planes.

Among the non-opaque heavy minerals, kyanite and tourmaline are the most abundant, while staurolite, rutile, and zircon are well represented. There are minor amounts of other non-opaque minerals present. The most noticeable feature of the assemblage is the abundance of the metamorphic minerals kyanite and staurolite, and the relatively low percentage of zircon. This is in marked contrast to the Greenough Sandstone, where zircon is comparatively abundant, while kyanite and staurolite are very rare.

Stratigraphic Relationships.—Over most of the area studied the Moonyoonooka Sandstone rests conformably on the Greenough Sandstone. However in those places where the Greenough Sandstone pinches out against hills in the Precambrian rocks, the Moonyoonooka Sandstone rests unconformably on these rocks.

The Moonyoonooka Sandstone is overlain disconformably by the Colalura Sandstone, the basal formation of the marine succession. This disconformity has little relief and is best seen in the Bringo cutting, where the phosphatic sandstone of the Colalura Sandstone rests on typical Moonyoonooka Sandstone, whose bedding planes are truncated at the surface of contact (see Plate 1, 1).

Distribution and Thickness.—The Moonyoonooka Sandstone has been recognised from near Kings Table Hill in the Northampton area to Mt. Hill. It extends inland as far as the Bringo cutting.

Throughout the area examined, wherever the Moonyoonooka Sandstone rests on Greenough Sandstone and not the Precambrian rocks, its thickness varies little from 110 feet, the thickest section measured being 118 feet at (713296), and the thinnest is 80 feet near Spion Kop (828326). The formation pinches out in those areas where the elevation of the Precambrian rises higher than 640 feet above sea-level.

The type section is the best known exposure of the formation. Another good outcrop is at (723310), where it has been exposed by gullying combined with landsliding. Other typical exposures occur at The Twins (608410), at Spion Kop (728327), and near "Woolanooka" (782337).

Fossils and Age.—Fragments of wood are the only fossils commonly found in the Moonyoonooka Sandstone. These are sometimes present in the centres of ferruginous concretions.

One fossil leaf has been found near the top of the type section, but this is poorly preserved and is of doubtful value for dating. Dr. A. B. Walkom is of the opinion (in a written communication) that it could be a leaf of the *Linguifolium* type, which would indicate a Mesozoic age, perhaps Jurassic or Rhaetic.

Owing to the lack of satisfactory fossil evidence it has not been possible to date the Moonyoonooka Sandstone, but it seems best considered as Lower Jurassic. It is probably equivalent to part of the Cockleshell Gully Sandstone of the Hill River area, and this formation has been dated as Lower Jurassic.

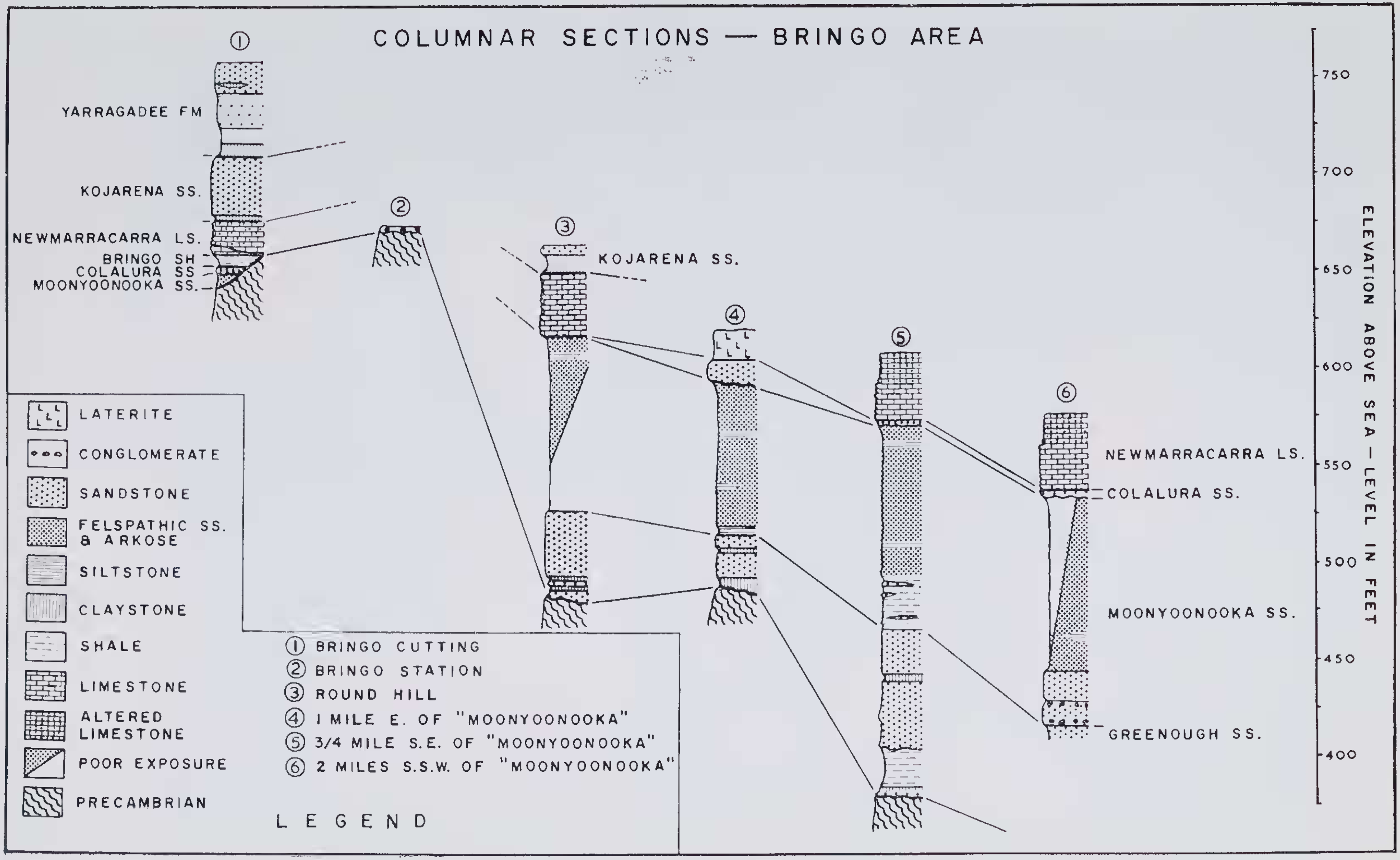
COLUMNAR SECTIONS — BRINGO AREA
ELEVATION ABOVE SEA — LEVEL IN FEET
750
700
650
600
550
500
450
400
YARRAGADEE FM
KOJARENA SS.
NEWMARRACARRA LS.
BRINGO SH
COLALURA SS
MOONYOONOOKA SS.
KOJARENA SS.
NEWMARRACARRA LS.
COLALURA SS.
MOONYOONOOKA SS.
GREENOUGH SS.
LATERITE
CONGLOMERATE
SANDSTONE
FELSPATHIC SS. & ARKOSE
SILTSTONE
CLAYSTONE
SHALE
LIMESTONE
ALTERED LIMESTONE
POOR EXPOSURE
PRECAMBRIAN
① BRINGO CUTTING
② BRINGO STATION
③ ROUND HILL
④ I MILE E. OF "MOONYOONOOKA"
⑤ 3/4 MILE S.E. OF "MOONYOONOOKA"
⑥ 2 MILES S.S.W. OF "MOONYOONOOKA"
LEGEND

Fig. 1.

1

2

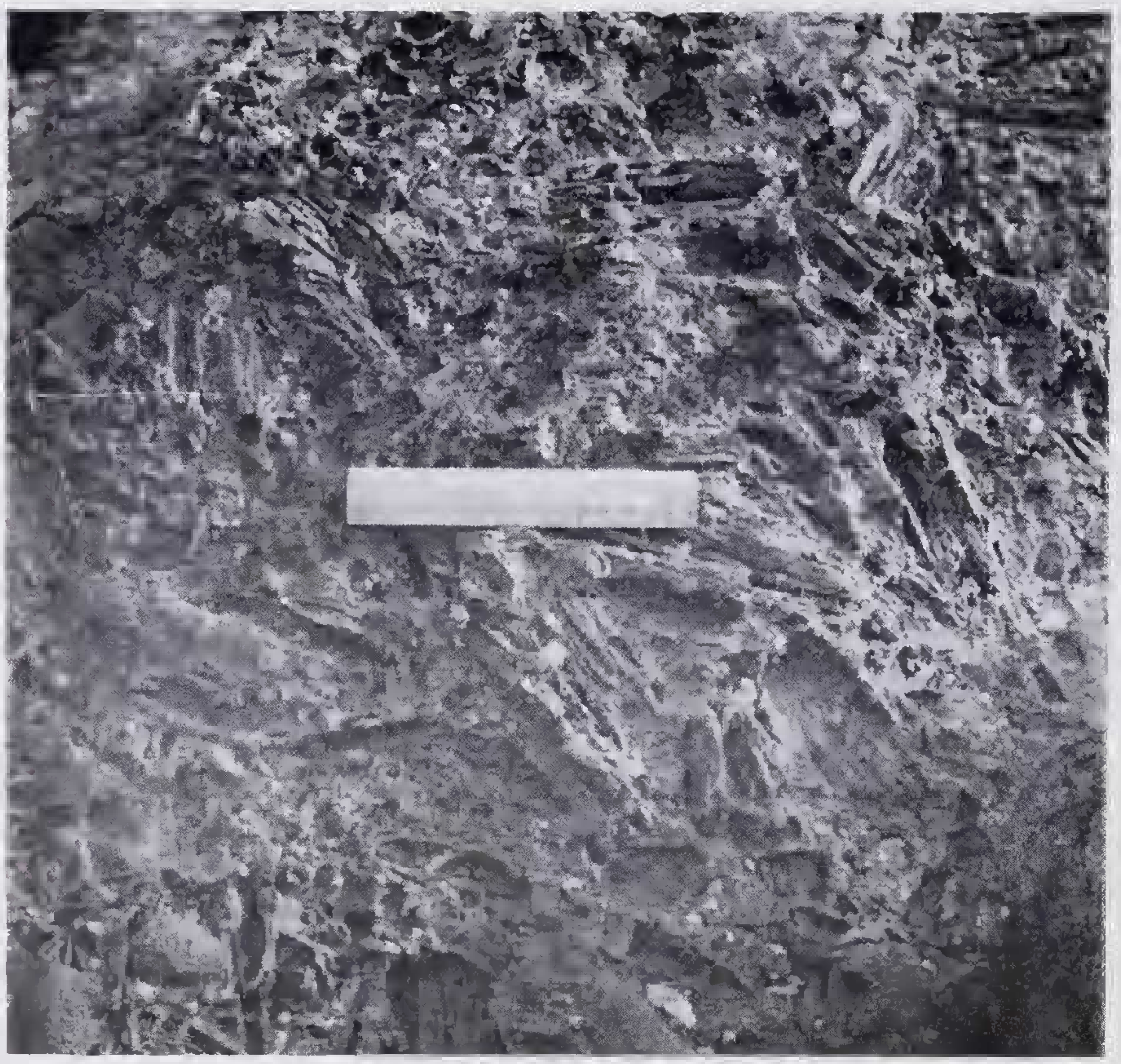

PLATE 1.

1.—Disconformity between Moonyoonooka Sandstone (beneath hammer) and Colalura Sandstone (about 18 inches thick) exposed in the Bringo cutting. The Colalura Sandstone is overlain conformably by Bringo Shale. Note truncation of bedding at the disconformity

2.—Exposure of Colalura Sandstone, showing abundant fossil wood enclosed in a matrix of ferruginous, conglomeratic sandstone. The scale is 6 inches long.

1

2

PLATE 2.

1.—Newmarracarra Limestone with numerous *Trigonia moorei*.

2.—Newmarracarra Limestone with several specimens of *Pecten cinctus*.

1

2

PLATE 3.

1.—The western end of the Bringo cutting, showing Jurassic sediments and kaolinized granitic gneiss (right centre). Note the two small west-dipping faults cutting the Jurassic sediments.

2.—Small anticline exposed in the Yarragadee Formation near the eastern end of the Bringo cutting.

Environment of Deposition.—The Moonyoonooka Sandstone is believed to be a continental fluviatile deposit. It shows the following features indicative of fluviatile deposition, many of which are also shown by the Greenough Sandstone:

(a) Fossil wood is present and one fossil leaf has been found, while marine fossils are absent.

(b) A prominent feature of the formation is the lenticular nature of individual beds, with sandstones, conglomerates, and shales dovetailing together in intricate fashion. This points strongly towards fluviatile deposition. The coarse sediments represent the channel deposits, and the finer-grained sediments the flood-plain deposits, while the dark shales represent deposits of small lakes and swamps on the flood-plain.

(c) The characteristic colour of the formation is yellow, a typical colour of fluviatile deposits which accumulate under non-reducing conditions, permitting preservation of such colours as red and yellow, which are due to ferric oxide.

(d) Intraformational conglomerates and breccias testify to the subaerial exposure of the beds.

(e) Cut-and-fill structure is present where coarse sandstones cut through shale or fine-grained sandstone.

(f) The abundance of cross-bedding and current ripple-mark throughout the formation is evidence of the shallow-water nature of the deposit.

(g) Arkose, though not invariably a fluviatile sediment, is most typically deposited under the fluvial environment, so that the prevalence of this sediment, together with felspathic sandstones, supports the suggested mode of origin of the formation.

It is considered that following deposition of the Greenough Sandstone, which rapidly filled major depressions in the surface of the Precambrian rocks, the Moonyoonooka Sandstone was spread over a broad flood-plain, above which some basement hills still projected, though the relief was much less than when the Greenough Sandstone was being deposited. The Moonyoonooka Sandstone is very well-bedded and well-sorted, in marked contrast to the Greenough Sandstone. This is because the Moonyoonooka Sandstone has been transported further than the Greenough Sandstone, and has been spread layer-on-layer by successive floods, whereas the Greenough Sandstone is locally derived.

The prevalence of fresh potash felspar in the Moonyoonooka Sandstone indicates that erosion of the source area was sufficiently rapid to prevent decomposition of this mineral. Rather rapid erosion is also indicated by the rich heavy mineral suite, which includes such relatively unstable minerals as sphene. The extreme rarity of garnet in the non-opaque suite is evidence that the sediment must have been transported a fairly considerable distance, for the local granitic rocks are rich in garnet. As the abundance of felspar and other metastable minerals is very marked in the Moonyoonooka Sandstone, garnet would also have been common had the sediment been locally derived.

It is likely that deposition of the Greenough and Moonyoonooka Sandstones, and indeed of all the continental Jurassic and Lower Cretaceous continental sediments in the Perth Basin, was controlled by movement along the Urella and Darling Faults. These sediments are believed to have been laid down in front of the active faults, and to have been derived by erosion of the area of steep, youthful topography near the fault scarps. The Urella Fault is believed to have been the dominant fault in Jurassic times in the area north of Coorow, while from about Coorow to the south coast the Darling Fault is the main fault. It is important to note that no Jurassic sediments are known in the area east of the Urella Fault.

Champion Bay Group

The name Champion Bay Group was introduced by Playford, in Arkell and Playford (1954), for the Jurassic sediments overlying the Chapman Group. The group is made up of four formations, the Colalura Sandstone, Bringo Shale, Newmarracarra Limestone, and Kojarena Sandstone. Playford and Willmott (in McWhae *et al.* 1958) redefined the Kojarena Sandstone, placing the upper part of the formation as previously understood by Playford in the Yarragadee Formation. The latter formation is not included in the Champion Bay Group.

The Champion Bay Group is of Middle Jurassic age. One formation, the Newmarracarra Limestone, is accurately dated as Middle Bajocian, and the other formations are probably also of Bajocian age.

(i) *Colalura Sandstone*

Definition.—The name Colalura Sandstone was introduced by Playford, in Arkell and Playford (1954), for the sandstone unit resting on the disconformity with the Moonyoonooka Sandstone or the nonconformity with the Precambrian rocks, and overlain conformably by the Bringo Shale or the Newmarracarra Limestone. The formation is named after the Colalura Brook (770330), which drains the southern part of the area surveyed in detail, and flows into the Greenough River.

The type section of the Colalura Sandstone is at Spion Kop (28° 46′ 44″ S., 114° 48′ 24″ E.). The following is a description of this section:

Laterite (lateritized Newmarracarra Limestone) overlying—

Colalura Sandstone (8 to 12′)

	Thickness feet
(1) Sandstone, very coarse- to medium-grained, conglomeratic, yellowish brown, ferruginous, coarsely cross-bedded, containing a few thin claystone beds; several horizons rich in fossil wood and limonitic nodules	8 - 12

disconformably overlying Moonyoonooka Sandstone.

Lithology.—The Colalura Sandstone consists almost entirely of sandstone, with minor amounts of claystone, siltstone, and shale. The sandstone is frequently conglomeratic, and varies in colour from black and brown to yellowish-white, a dark brown being most common. Sand grains may be appreciably rounded or unrounded, and their cement is usually ferruginous, but is sometimes calcareous.

A striking and characteristic feature of most exposures of the unit is the presence of abundant ferruginous fossil wood (see Plate 1, 2), and to a lesser extent of oval-shaped ferruginous nodules, generally about ¾-inch long. The wood varies in size from logs 3 feet long, to minute fragments. The nodules and some of the fossil wood are believed to have been originally phosphatic, and to have been ferruginized during weathering. They are still phosphatic in the exposures of Colalura Sandstone in the Bringo cutting and near "Woolanooka" (780238).

The phosphatic nodules, which are dark brown in colour, have a pronounced concentric structure, and frequently contain a nucleus of greyish clay. It is possible that this structureless clayey interior is of coprolitic origin, and the nodule has grown by concentric addition to this nucleus. In the nodules which have been replaced by limonite, this concentric structure is lost, though the clay centres remain.

The nodules are apparently syngenetic (formed before burial in sediments), for the insoluble residue left after treatment of the nodules with acid is fine clay or sand, despite the fact that the nodules are themselves enclosed in a coarse sand.

The abundant limonite in the Colalura Sandstone is probably not entirely secondary, for even in the Bringo cutting where the nodules are still phosphatic, the cementing agent in the sandstone is limonite, with perhaps some hematite, and the nodules themselves contain some ferric oxide. The reason for the complete replacement of the nodules by ferric oxide is not certain, but it may well be connected with lateritization.

Stratification is usually absent in the sandstones, though they are sometimes coarsely cross-bedded. The sorting of the sandstones usually appears to be poor owing to the large amounts of fossil wood and nodules present—these may make up as much as 50% or more of the rock by volume. However, the sand remaining after treatment of the rock with acid is often found to be quite well-sorted.

In the Bringo cutting the Colalura Sandstone shows a well-marked facies change from the typical brown sandstone with no marine fossils but abundant dark brown fossil wood and phosphatic nodules, to a yellowish sandy claystone with abundant marine fossils, and occasional fossil wood and phosphatic nodules. The nodules and fossil wood in this claystone are different in appearance from those in the sandstone, and they also contain a higher percentage of P_2O_5. The phosphatic wood is yellow, and the cell structure is clearly visible, even to the naked eye. This fossil wood contains as much as 32.9% of P_2O_5, whereas the fossil wood in the sandstone from the cutting contains only as much as 1.47% of P_2O_5. The nodules in the claystone are yellowish and many have a black coating giving them a high surface lustre. In shape they are similar to the typical brown nodules, and they usually contain a clayey nucleus, though the outer layer shows no pronounced concentric structure. These nodules have as much as 23.8% of P_2O_5, while the dark brown nodules from the sandstone contain up to 6.1%.

The cementing material of the Colalura Sandstone is occasionally calcareous, as at the locality near "Woolanooka" (780238), and at (873307), near "Sandspring."

In some localities the sandstone is stained black by manganese oxide. This is seen well in the Bringo cutting, where the sandstone and claystone of the formation show some black patches due to a thin coating of manganese oxide.

The "light" minerals in the sandstone remaining after treatment with acid consist of rounded and angular grains of quartz, and smaller amounts of felspar and muscovite. The percentage of felspar was not sufficient to designate any of the samples examined as being felspathic, but it is higher than in any formation other than the Moonyoonooka Sandstone. Only potash felspar has been recognized, and the percentage is highest in the finer-grained sandstones, one sample containing 8%.

The heavy mineral suite is rather variable, the most distinctive feature being the abundance of the metamorphic minerals kyanite, staurolite, and garnet. The nature of the heavy mineral suite seems to vary according to the underlying rock. In the Bringo cutting the Colalura Sandstone rests on both the Moonyoonooka Sandstone and the Precambrian gneisses. The heavy mineral residue from the formation at this locality is remarkable for its unusually large content of garnet, which forms more than 50% of the non-opaque minerals. The Precambrian gneisses of this area are very rich in garnet, and the Colalura Sandstone in the Bringo cutting no doubt derived its garnet from this source. On the other hand, specimens examined from localities distant from granitic areas, where the formation overlies thick deposits of Moonyoonooka Sandstone, contain little or no garnet. These specimens are found to contain considerable quantities of kyanite and staurolite, which were probably derived by the reworking of the underlying Moonyoonooka Sandstone, which is rich in these minerals, but contains little garnet.

Stratigraphic relationships.—The Colalura Sandstone usually overlies the Moonyoonooka Sandstone, being separated by a disconformity which shows little relief. In places however, it overlies the Precambrian rocks, as the Moonyoonooka Sandstone lenses out against buried hills. Conformably overlying the Colalura Sandstone is either the Bringo Shale or the Newmarracarra Limestone.

Distribution and thickness.—The Colalura Sandstone is a thin, discontinuous, but persistent formation at the base of the marine section throughout a large part of the Geraldton district.

It is known to extend from near Howatharra Siding (north of the map) to Mt. Hill, and has been recognized as far east as "Sandspring" (873307).

The Colalura Sandstone is absent over part of the area, but where present it ranges up to 28 feet in thickness at (725340). Most exposures are only about 2 feet thick.

As the Colalura Sandstone is often well-consolidated, exposures of the formation are quite frequent, in the form of large slabs, which may migrate some distance down the hill-slopes.

Fossils and age.—As already described, the Colalura Sandstone is rich in fossil wood. Marine fossils have also been found in the formation at several localities. The most important of these is the Bringo cutting, where a claystone unit in the formation contains numerous marine fossils, preserved as moulds. Another locality where fossils are abundant is at (715325), where they are preserved as moulds in a coarse-grained ferruginous sandstone.

The following is a list of fossils which have been identified from the Colalura Sandstone: The pelecypods *Astarte cliftoni*, *Astarte* sp., *Ctenostreon pectiniformis*, *Lopha* cf. *marshi*, *Trigonia moorei*, *Ostrea* sp., *Oxytoma* cf. *decemcosta*, and *Isognomon* sp., and the belemnite *Belemnopsis* sp.

There are also several unidentified species of pelecypods and gastropods, and one echinoid spine, a shark tooth, a reptilian tooth, and a reptilian vertebra were found in the Bringo cutting.

All the species which have been identified are also present in the Newmarracarra Limestone, which is known to be of Middle Bajocian age, and it seems probable that the Colalura Sandstone is also Bajocian in age.

Environment of deposition.—The Colalura Sandstone represents the basal shallow-water deposits of an advancing sea. The clastic constituents were largely derived by reworking from the underlying Moonyoonooka Sandstone and the Precambrian rocks. A shallow-water environment of deposition is indicated by the coarseness of the sandstone and the large-scale cross-bedding. Moreover, it is difficult to visualize such large quantities of wood being incorporated in the sediment except under very shallow water conditions.

The source of all the fossil wood in the formation is not easy to explain. If it has been carried in by rivers, then the sediments carried by those rivers would tend to mask the wood. It is possible that the wood represents the vegetation which was growing on the low-lying flood-plain of the Moonyoonooka Sandstone, which was engulfed as the sea advanced. Against this hypothesis is the fact that no fossil stumps have been found embedded *in situ* in the Moonyoonooka Sandstone.

The origin of the phosphatic nodules in the formation is not known. However the occurrence of these nodules immediately above the disconformity with the Moonyoonooka Sandstone is not unexpected, as phosphatic zones are commonly found elsewhere in the world in association with unconformities.

(ii) *Bringo Shale*

Definition.—The name Bringo Shale was first used by Playford, in Arkell and Playford (1954), for the black shale which overlies the Colalura Sandstone or the Precambrian rocks, and underlies the Newmarracarra Limestone.

The type section is exposed in the Bringo cutting (766364, 28° 44′ 54″ S., 114° 50′ 54″ E.) The following is a description of this section:

Newmarracarra Limestone. Comformably overlying—

Bringo Shale (7 feet)

	Thickness Ft.	In.
(5) Shale, black, becoming yellow in the uppermost foot; phosphatic nodules resting on top; several layers containing small pelecypods	2	6
(4) Claystone, yellowish brown, phosphatic, concretionary		2
(3) Shale, black; rich in small pelecypods		6
(2) Claystone, yellowish brown, phosphatic, concretionary		4
(1) Shale, black; abundant small pelecypods at the base	3	6

conformably overlying Colalura Sandstone.

Lithology.—The Bringo Shale consists of black shale with thin yellow phosphatic beds. A layer of phosphatic nodules is present at the top of the unit, at the contact with the Newmarracarra Limestone. The shale contains some small carbonaceous fragments of wood and a few beds of marine fossils.

The yellow phosphatic clay beds are only a few inches thick, and show pronounced concretionary structures. The phosphate content averages 3.3% of P_2O_5. The phosphatic nodules, which are not common, are flattened, smooth, bulging, asymmetrical bodies, which are up to 6 inches long, and 2 inches thick. They show only a poorly defined concentric structure. The upper surface of the nodules often shows a series of small pits. Sections show that these pits cut through the concentric structure of the nodules, indicating that they are secondary, and it seems possible that they were formed by boring organisms. Another feature of the outer surface is a series of cracks which penetrate about ¼-inch into the nodules. These are sub-parallel, and are apparently shrinkage cracks produced when the nodules solidified. The phosphate (P_2O_5) content of the nodules varies from 7.6% in the Bringo cutting to 26.8% near "Sandspring".

Stratigraphic relationships.—The Bringo Shale rests conformably on the Colalura Sandstone, or unconformably on the Precambrian rocks. Both relationships are visible in the section exposed at the Bringo cutting.

Overlying the Bringo Shale is the Newmarracarra Limestone. A layer of phosphatic nodules at the contact between the formations suggests an interval of non-deposition, so that they are probably separated by a diastem, though they are essentially conformable.

Distribution and thickness.—The Bringo Shale has a rather limited distribution. It has been traced at the surface from the Bringo cutting to near "Sandspring" (872307), and as far south as (848249). It is probably present in bores in the Eradu area, underlying the Kojarena Sandstone, and resting on the Lower Permian Irwin River Coal Measures.

The Bringo Shale appears to have been deposited only in the restricted environment lying to the east of Precambrian ridges. Thus the unit is present in the Bringo cutting section, to the east of a Precambrian ridge which reaches its highest point near Bringo Station, but it is absent on the western side of this ridge, in the Grant Siding—"Moonyoonooka" area (see section A-B, Plate 5, and Fig. 1.)

No section of the formation has been seen which is more than 8 feet thick, and where it rests on the Colalura Sandstone it is usually about 7 feet thick. At the type section the thickness is 7 feet, near "Sandspring" (872307) it is 8 feet, and at (848249) it is 5 feet.

The Bringo Shale is poorly exposed throughout the area examined. The best section is the Bringo cutting, but elsewhere there is no continuous section exposed.

Springs commonly issue at the contact between the Newmarracarra Limestone and the Bringo Shale, and the running water often exposes the shale to some extent. A typical example is found one mile east of Bringo (775358), where there is a good spring of fresh water issuing at the contact between the two formations.

Fossils and age.—The only fossils which have been found in the Bringo Shale are those from the type section. At this locality there are several layers in the shale which are rich in dwarfed pelecypods, predominantly a species of *Meleagrinella*, together with some oysters. Rare gastropods, and guards of *Belemnopsis* are also found. Balme (1957) has described a small assemblage of fossil spores and pollen grains in a sample of the formation from the Bringo cutting.

The Bringo Shale is believed to be of Bajocian age. The layer of phosphatic nodules at the top of the formation indicates a probable gap in sedimentation prior to deposition of the Middle Bajocian Newmarracarra Limestone, but this gap was probably only of very short duration.

Environment of Deposition.—The Bringo Shale was deposited in an environment having restricted circulation, resulting in anaerobic conditions on the bottom. Under such conditions the benthonic fauna is absent or restricted, and the action of scavengers in eliminating organic material derived from the surface waters is prevented. Nearly all black shales in the geological record are believed to have formed in this way (Twenhofel 1950).

As the Bringo Shale contains several layers with dwarf benthonic pelecypods, and as no iron sulphide has been found in the shale, restriction of circulation was apparently not complete, and there were periods when the bottom was quite well-oxygenated. However, as the benthonic fossils are only found in relatively thin bands, with black unfossiliferous shale in between, the conditions were apparently anaerobic during most of the time when the shale was accumulating.

The cause of the stagnation is to be found in the irregularity of the surface of the Precambrian rocks. It is clear in the Bringo cutting that the shale has accumulated in a barred basin on the eastern side of a hill or ridge of Precambrian rocks. On the western side of this ridge the Bringo Shale is absent, as this area was apparently part of the open ocean, with free circulation, at the time when the shale was accumulating in the restricted environment to the east of the ridge. It is not known whether the ridge was below sea-level when the shale was deposited. If it was submerged, the depth of water must have been small, so that free connection with the open ocean was prevented.

Some change must have occurred in the conditions of circulation following deposition of the Colalura Sandstone. In the Bringo cutting section this formation contains a rich benthonic fauna which clearly grew under normal conditions of free circulation. It is possible that during Colalura times there was free connection with the open ocean through some opening which was barred before deposition of the Bringo Shale commenced. Alternatively the restriction may have followed a slight relative fall in sea-level, making the bar more effective.

The phosphatic nodules at the top of the formation may have been deposited in the form of a gel. This is suggested by their flattened, irregularly rounded shape, which is typically like that of a gel mass, and also by the presence of skrinkage cracks on the outer surface of the nodules. These may have formed as the gel contracted on solidification.

(iii) *Newmarracarra Limestone*

Definition.—The Newmarracarra Limestone was defined by Playford, in Arkell and Playford (1954). The formation overlies either the Bringo Shale, the Colalura Sandstone, the Moonyoonooka Sandstone, or the Precambrian rocks, and underlies the Kojarena Sandstone. The name is taken from "Newmarracarra," a well-known pastoral property in the Geraldton district.

The name "Newmarracarra" had previously been used in a stratigraphic sense by Glauert (1926), who defined the "Newmarracarra Beds" as the fossiliferous beds exposed in the "Nineteen Mile" (later Bringo) railway cutting, from which the fossils described by Whitehouse (1924) were obtained. Actually Whitehouse's fossils were probably obtained from a railway well near Bringo, but in either case they certainly came from the limestone, and Glauert's name must be used in reclassification.

Teichert (1947), apparently independently, proposed the name "Newmarracarra Series" for all the marine sediments of the Geraldton district, but Glauert's earlier usage clearly has priority.

The type section of the formation is on Round Hill, near Grant Siding (729351, 28° 45′ 31″ S., 114° 48′ 23″ E.) The following is a description of this section:—

Kojarena Sandstone. Conformably overlying—

Newmarracarra Limestone

	Thickness Feet.
(4) Limestone, light yellow-grey, sandy, hard, massive, outcropping in large slabs; few fossils	2
(3) Limestone, light yellow-grey, weathering greyish white, hard, massive, outcropping in large slabs; richly fossiliferous	8
(2) Limestone, light yellow-grey, clayey, soft, massive; richly fossiliferous ...	21
(1) Limestone, light yellow-grey, sandy, clayey, hard, massive, outcropping as large slabs, richly fossiliferous	2

disconformably overlying Moonyoonooka Sandstone.

Lithology.—The Newmarracarra Limestone, where it has not undergone secondary alteration, usually consists of limestone composed of entire or little-broken shells. It has a variable content of clastic impurities, and rarely grades into a calcareous sandstone.

The limestone is generally massive, hard, and smooth-weathering, outcropping as large slabs which frequently break off, and tend to migrate down the sides of hills making it difficult to say when the slabs are *in situ*.

The colour of the limestone varies from yellow and grey to red, the most usual being yellow, frequently weathering grey. The red coloration is secondary, and is due to the presence of finely divided hematite in the rock.

The limestone has been subjected to a great deal of secondary alteration throughout the area examined. Over the most of this area a large part of the limestone has been either replaced by iron oxide (mainly hematite), or leached of calcium carbonate, leaving a residue of its clastic impurities. Only in the small area around the type section near Grant is the limestone thought to be unaltered throughout, and even there it is possible that the sandy claystone overlying the limestone outcrop is really leached limestone. The leached zone is found between the hematite and the unaltered limestone, and the thickness of alteration is very variable. This alteration of the limestone is connected with lateritization, and has been discussed already.

The limestone is often stained red by hematite without complete removal of calcium carbonate. This is not connected with lateritization and is often found where the limestone overlies Bringo Shale, with springs issuing at the contact.

The insoluble residue from the limestone consists of clay, rounded grains of quartz, a little felspar, an occasional flake of muscovite, and a small quantity of heavy minerals. The percentage of these clastic impurities is usually rather high, most samples being sandy, argillaceous limestones. The quartz sand present is rounded, having an average roundness of about .29. This value is considerably higher than that for sand in the other formations, and indicates relatively prolonged abrasion of the sand.

It is noticeable that the percentage of clastic impurities in the formation rises to the east, as those elevated areas in the Precambrian rocks still projecting above the earlier sediments are approached. For example, on the road from Northern Gully to "Tibradden" (836367), there is an outcrop of cross-bedded calcareous sandstone at the base of the limestone, and all the limestone is very sandy. The formation abuts a buried hill of Precambrian rocks near this locality, and almost certainly pinches out against this hill. On the other hand the base of the limestone to the west (as at (690297), which is several miles from such elevated Precambrian areas) is comparatively free of clastic impurities.

The high sand content around the granitic hills is probably not due to erosion of these hills when the Newmarracarra Limestone was accumulating. This is indicated by the fact that the quartz grains are comparatively well-rounded, and must have undergone rather prolonged abrasion before deposition. They could not have been abraded to any great extent while the shells were accumulating, for these show little evidence of wear. It is probable that the sand was rounded while the Colalura Sandstone and Bringo Shale were being deposited. During this time the sea probably did not cover the granitic hills, and rounded beach sands may have accumulated around these islands or promontories. The rounded sand now found in the limestone may represent this sand which was redistributed during deposition of the Newmarracarra Limestone.

The most striking feature of the heavy mineral suite is the unusually large quantity of epidote present, as this mineral is only found in small quantities in the other formations. Otherwise the heavy mineral assemblage is rather like that of the Colalura Sandstone, with a fairly high percentage of metamorphic minerals, including garnet.

Stratigraphic relationships.—The Newmarracarra Limestone was deposited in different parts of the area on either the Bringo Shale, the Colalura Sandstone, the Moonyoonooka Sandstone, or the Precambrian rocks. The contact with the Precambrian rocks is a nonconformity, and that with the Moonyoonooka Sandstone is a disconformity. The contact with the Bringo Shale and the Colalura Sandstone is believed to be essentially conformable, though the units may be separated by a diastem.

The Newmarracarra Limestone is overlain conformably by the Kojarena Sandstone.

Distribution and thickness.—Unaltered Newmarracarra Limestone has a very limited distribution in the Geraldton district, the most extensive outcrops being found in the area mapped in detail. Elsewhere outcrops are very sporadic, as the limestone has been largely altered by lateritization. The hematite rock and underlying leached zone can be readily recognized as altered Newmarracarra Limestone in the field, and have been mapped as such. On the other hand, the intensely altered limestone close to true laterite is not readily recognized, and for mapping purposes has been included in the laterite.

Owing to the irregular alteration, the thickness of limestone is very variable, the thickest exposures being near Round Hill, where up to 33 feet of unaltered limestone are exposed. Elsewhere the formation is invariably altered to some extent, so that at least the upper part is replaced by hematite or simply leached of calcium carbonate. Because of the irregular leached zone, which causes compaction of the formation, it is not possible to give accurate primary thickness of the limestone at those localities where it has been altered. The thickest section which has been measured is at (690297), where the formation is about 38 feet thick. At this locality there are about 28 feet of limestone and 10 feet of altered limestone. Nearly all of this alteration is in the form of hematite, and the leached zone is very thin. In the Geraldton Racecourse bore the formation may be 47 feet thick (from 186 feet to 233 feet).

At the Bringo cutting the unaltered limestone is up to 5 feet thick, but passes both laterally and vertically into leached limestone (see Plate 6). The leached zone is up to 8 feet thick, and is overlain by as much as 9 feet of hematite rock. The contact between the leached and hematite-replaced limestone is not well-marked, each grading gradually but irregularly into the other. At this locality the formation is only 17 feet thick, and has compacted considerably owing to the thick leached zone.

Exposures of the Newmarracarra Limestone extend from near Howatharra Siding on the Geraldton-Northampton line (off the map) to Mt. Hill. It is known to lense out to the east, and has been recorded during the recent Wapet survey as far inland as 1½ miles south-east of Eradu Pool on the Greenough River. It is absent from bores around Eradu itself, though both the Kojarena Sandstone and the Bringo Shale are apparently represented there.

The Cadda Formation of the Hill River area, 100 miles south of Geraldton, is a facies equivalent of the Newmarracarra Limestone. The Cadda Formation contains a high percentage of sandstone and siltstone in addition to limestone, and is also not as richly fossiliferous as the Newmarracarra Limestone.

Fossils and age.—The Newmarracarra Limestone is richly fossiliferous, and fossils are usually well-preserved, though they are frequently difficult to extract owing to the toughness of the matrix. In addition to the abundant marine fossils, fragments of wood up to about 2 feet long are not uncommon in the limestone.

The most abundant fossils are the pelecypods, and of these *Trigonia moorei* is by far the most common. This species is found, perfectly preserved, in great abundance thoroughout the formation, indeed some parts are composed almost entirely of masses of this shell (see Plate 2, 1).

The ammonites, which are of prime importance in dating the formation, are seldom found in any abundance, though there are at least 23 species known. The species most commonly found is *Fontannesia clarkei* and large numbers of this species were collected in the debris from rabbit-burrows in the area about one mile south-east of Bringo. The ammonites have recently been the subject of a detailed study by Arkell (in Arkell and Playford 1954), and he has concluded that the Newmarracarra Limestone can be referred to the Sowerbyi and perhaps Sauzei and Humphriesianum Zones of the European Middle Bajocian.

The following is a list of fossils which have been recorded from the Newmarracarra Limestone. It must be understood that most of these fossils were described many years ago, and many of the names, particularly of the genera, need revision. These forms marked with an asterisk, e.g. **Cristellaria cultrata*, have not been figured or properly described from the Newmarracarra Limestone. Their occurrence has merely been recorded, and there is some doubt as to whether some of them are really present. The Ostracoda, originally described by Chapman (1904*a*), were recently discussed by Kellett and Gill (1956), and they point out that the fauna needs complete re-study. It is certain that all the fossils which have previously been described as coming from the Geraldton district are from the Newmarracarra Limestone.

Foraminifera (Chapman 1904*a*, Moore 1870). *Bulimina gregorii, Cristellaria costata* var. *compressa, C. costata* var. *seminuda*, **C. cultrata, C. daintreei, C. decipiens, C.* cf. *limata, C. prominula, C. rotulata, C. subalata, Discorbina rosacea, Flabellina dilatata, Haplophragmium neocomianum, Marginulina compressa, M. solida, Polymorphina burdigalensis, P. compressa, P. gutta, Textularia crater, Truncatulina wuellerstorfi, Vaginulina intumescens, V. lata, V. schloenbachi* var. *interrupta, V. strigillata.*

Echinoidea (Whitehouse 1924). *Cidaris* sp.

Vermes (Clarke 1867, Moore 1870, Etheridge 1910). *Serpula conformis*, **Serpula* spp.

Byozoa (Whitehouse 1924). **Berenicea* cf. *archiaci.*

Brachiopoda (Clarke 1867, Moore 1870, Etheridge 1910). *Rhynchonella variabilis*, **Rhynchonella* spp.

Pelecypoda (Clarke 1867, Moore 1870, Etheridge 1901, Maitland 1907, Etheridge 1910, Glauert 1910, Whitehouse 1924, Teichert 1940). **Arca* sp., *Lopha marshi*, **Avicula inaequivalvis, Ctenostreon pectiniformis, Cucullaea inflata*, **C. oblonga, C. semistriata, C. tibraddonensis, Meleagrinella sinuata*, **Gryphaea* spp., **Hinnites* sp., **Lima proboscidea* Sowerby, **L. punctata, Modiola maitlandi*, **Mytilus* cf. *gygerensis*, **M. sp.*, **Nucula* sp., *Ostrea tholiformis, Ostrea* spp. *Oxytoma decemcosta*, **Pecten calvus, P. cinctus*, **P.* cf. *frontalis, P. greenoughensis*, **P. valoniensis*, **P.* spp., **Perna sp., Plicatula* sp., *Radula duplicata*, **Radula* sp., *Trigonia moorei*, **Gresslya donaciformis*, **Myacites liassianus, M. sanfordii*, **Pholadomya ovulum, Astarte apicalis, A clijtoni*, **Cardium* sp., **Cypricardia* sp., **Isocardia* sp., **Lucina* sp., **Opis* sp., **Panopaea rugosa*, **P.* sp., **Tancredia* sp., *Teredo australis*, **Unicardium* sp.

Scaphopoda (Clarke 1867). **Dentalium* sp.

Gastropoda (Clarke 1867, Moore 1870, Etheridge 1910). **Amberleya* sp., **Phasianella* sp., *Pleurotomaria greenoughensis*, **Pleurotomaria*, sp.,**Trochus* sp., *Turbo laevigatus*, **Turbo* sp., *Cerithium greenoughensis*, **C.* sp., **Chemnitzia* sp., **Nerinaea* sp., *Rissoina australis*.

Nautiloidea (Crick 1894). *Nautilus perornatus*.

Belemnoidea (Clarke 1867, Moore 1870, Crick 1894, Whitehouse 1924). *Belemnites canaliculatus*, **Belemnites canhami*, **B.* sp., *Belemnopsis* sp.

Ammonoidea (Arkell and Playford 1954). *Sonninia playfordi*, *Witchellia australica*, *Fontannesia fairbridgei*, *F. clarkei*, *F. whitehousei*, *F.* spp., *Otoites woodwardi*, *O. antipodus*, *O. (?Trilobiticeras) depressus*, *?O. australis*, *Pseudotoites leicharti*, *P. fasciculatus*, *P. championensis*, *P. robiginosus*, *P. emilioides*, *P. brunnschweileri*, *P. spitiformis*, *P. semiornatus*, *P. spp.*, *Zemistephanus* corona, *Z. armatus*, *?Z.* spp., *Stephanoceras (Stemmatoceras)* cf. *subcoronatum*, *S. (S.)* aff. *triptolemus*.

Ostracoda (Chapman 1904*a*, Kellett and Gill 1956). *"Cythere" lobulata*, *"Cytheropteron" australiense*, *"Loxoconcha" elongata*, *"L." jurassica*, *Procytheridea* sp.

Environment of deposition.—The Newmarracarra Limestone is built up for the most part of the remains of shallow-water benthonic organisms, predominantly pelecypods, which accumulated on the bottom of a shallow, warm sea. Currents introduced a certain amount of clay, silt, and sand, but the fact that these fossils show little evidence of wear, and the pelecypod valves are often closed, indicates that these currents were not very strong. There was also a certain amount of drift wood in the sea, which on becoming waterlogged, sank to the bottom and was incorporated in the limestone.

Following deposition of the Bringo Shale, there must have been a further subsidence (relative rise in sea-level) before deposition of the Newmarracarra Limestone. This subsidence explains the change in environment from one of restricted circulation during deposition of the Bringo Shale, to one of open circulation for the Newmarracarra Limestone. By covering or increasing the depth of water over the elevated Precambrian ridges, the region east of these ridges obtained good circulation.

(iv) *Kojarena Sandstone*

Definition.—The name Kojarena Sandstone was first published by Playford in Arkell and Playford (1954). He defined it as the Jurassic sediments, mainly sandstones, which overlie the Newmarracarra Limestone in the Geraldton district. The name is taken from Kojarena, a small railway siding on the Geraldton-Mullewa line. However, the limits of the formation have since been revised by Playford and Willmott in McWhae *et al.* (1958), the upper part of the formation as previously understood being included in the Yarragadee Formation.

The type section of the Kojarena Sandstone is in the Bringo railway cutting (28° 44′ 54″ S., 114° 50′ 54″ E.). The following is a description of this section:

Yarragadee Formation. Conformably overlying—

Kojarena Sandstone (33′)

	Thickness feet.
(2) Sandstone, reddish brown, the lower half being mottled grey, brown, and yellow; bedding indistinct; marine fossils in a lens up to 6 inches thick, 19 feet above the base	31
(1) Claystone, greyish white, mottled red; poorly bedded	2

conformably overlying Newmarracarra Limestone.

Lithology.—The Kojarena Sandstone is composed predominantly of brown ferruginous sandstone, with a little claystone at the base. The sandstone is medium- to coarse-grained, and is generally very well-sorted. The unit is poorly bedded to massive, though cross-bedding is sometimes present.

The sandstones are composed of subangular grains of quartz, with little or no felspar, and small quantities of heavy minerals. Compared with the preceding marine formations the heavy mineral suite is marked by an increased percentage of the ultra-stable minerals zircon and tourmaline, and a corresponding fall in the quantity of metamorphic minerals.

Stratigraphic Relationships.—The Kojarena Sandstone is found overlying the Newmarracarra Limestone, with apparent conformity, throughout most of the area examined. In one area near Wicherina (945350) the Newmarracarra Limestone is sometimes overlain directly by the Yarragadee Formation, while in bores around Eradu (to the east of the area covered by Plate 4) the Kojarena Sandstone appears to rest on the Bringo Shale. Further north, near the mouth of Kockatea Gully, the Kojarena Sandstone disconformably overlies the Upper Permian or Lower Triassic Kockatea Shale.

The Kojarena Sandstone is overlain, with apparent conformity, by the Yarragadee Formation.

Distribution and Thickness.—The Kojarena Sandstone is the most widely distributed of the Middle Jurassic marine formations. It extends from Howatharra Siding (off the map) to Mt. Hill, and inland it is found all along the valley of the Greenough River north and south of Eradu and the lower reaches of Kockatea Gully. The unit is probably present in the Geraldton Racecourse Bore between 154 and 186 feet.

In the area around Eradu the unit probably reaches its thickest development. The thickness from bores and exposures in this area is probably about 110 feet, whereas in the Geraldton area it does not exceed 33 feet, the thickness of the type section. It is not present in the 47¼ mile peg bore (off the map) which is situated close to the Urella Fault. In this bore the Yarragadee Formation rests directly on the Kockatea Shale.

Fossils and age.—The Kojarena Sandstone contains few fossils. In the Bringo cutting section at 20 miles 5 chains from Geraldton, there is a thin fossiliferous lens up to 6 inches thick containing moulds of marine fossils. At several other localities, such as Round Hill and $1\frac{1}{2}$ miles east-north-east of Eradu, a few similar marine fossils have been found. Those which have been identified are *Trigonia moorei*, *Cucullaea* sp., *Isognomon* sp.,and *Belemnopsis* sp. These fossils are also present in the underlying Newmarracarra Limestone, which is of Middle Bajocian age. As the two formations are comformable, it is likely that the Kojarena Sandstone is also of Bajocian age.

Fragments of wood occur occasionally in the unit, and worm tubes are also sometimes found.

Environment of deposition.— The Kojarena Sandstone is interpreted as being a shallow-water marine deposit. The presence of marine fossils in typical sandstones of the formation shows the marine origin, and the high degree of sorting probably indicates that it was deposited below wave-base. It represents the final phase of the Middle Jurassic marine cycle.

Yarragadee Formation

Definition.—The Yarragadee Formation was first named "Yarragadee Beds" by Fairbridge (1953). He used the name for exposures of sandstone and siltstone on Yarragadee property, 7 to 8 miles north of Mingenew. His usage was followed by Johnson *et al.* (1954). The name was raised to formation rank by Playford and Willmott (in McWhae *et al.* 1958). They included the "Monksleigh Beds" of Fairbridge (1953) in the formation. Fairbridge's type locality of the "Yarragadee Beds," $1\frac{1}{2}$ miles south-south-east of Yarragadee Homestead, is retained as the type of the Yarragadee Formation. However, the section exposed there is complicated by faulting (it is adjacent to the Urella Fault), and a satisfactory section cannot be measured.

The section of Yarragadee Formation exposed in the Bringo railway cutting is proposed as a reference section for the formation in the Geraldton area. This section is as follows:

Yarragadee Formation ($51\frac{1}{2}$)

Top of formation not exposed, overlain by Quaternary deposits.

	Thickness feet
(13) Sandstone, silty, coarse-grained, light yellowish brown; poorly sorted	1
(12) Claystone, white, unbedded, lenticular.	$\frac{1}{2}$
(11) Sandstone, silty, coarse-grained, light yellow-brown, unbedded, poorly sorted.	2
(10) Claystone, silty, white, unbedded; contains rare cannon-ball concretions; lenticular	$1\frac{1}{2}$
(9) Sandstone, silty, coarse-grained, conglomeratic in part, light yellow-brown unbedded, poorly sorted; quartz grains subangular	8
(8) Claystone, greyish white, unbedded, lenticular	1
(7) Sandstone, medium-grained, yellow-brown, well-sorted, unbedded; quartz grains are sub-angular; contains a few dark brown cannon-ball concretions....	3
(6) Siltstone, sandy, with some interbedded fine-grained silty sandstone and claystone; variegated yellow, white, and red, thinly-bedded, partly cross-bedded; contains some thin ferruginous bands and cannon-ball concretions	$6\frac{1}{2}$
(5) Shale, silty in part, grey, grading into siltstone, white to light grey; contains a few thin jarositic bands ..	$5\frac{1}{2}$
(4) Siltstone, sandy, white to yellowish white, thinly bedded to fissile, grading into fine-grained silty sandstone; contains thin beds of grey claystone, which is partly carbonaceous	6
(3) Claystone, dark grey, carbonaceous, grading into siltstone; poorly bedded, containing carbonaceous wood fragments; yellow jarositic beds, irregular in shape, are present; an efflorescence of minute gypsum crystals is present in places	$5\frac{1}{2}$
(2) No exposure, due to channel filled with alluvium	4
(1) Claystone, sandy, silty, greyish white to grey, mottled pink, poorly bedded, weathered; contains few thin yellow-brown ferruginous beds	7

conformably overlying Kojarena Sandstone.

Lithology.—The Yarragadee Formation is an interbedded sequence of sandstone and siltstone, with lesser thicknesses of shale, claystone, and conglomerate. The sandstones are mainly poorly sorted, and are very coarse- to medium-grained. They are partly felspathic, though the felspar is usually kaolinized at the surface. Exposures of the sandstones are commonly white, with a mottled red-and-yellow colouring. The siltstones are micaceous, and are usually white at the surface, though in the subsurface they are often dark grey and carbonaceous. Bedding in the sandstones is generally poor, though cross-bedding is sometimes developed. The siltstones are often thinly bedded to fissile.

Stratigraphic relationships.—In the Geraldton area the Yarragadee Formation rests with apparent conformity on the Kojarena Sandstone, and the top is eroded or capped by laterite.

Distribution and thickness.—The Yarragadee Formation is known to extend from near Howatharra Siding in the north to the Moore River in the south. In the Geraldton-Mingenew area it is known to extend no further inland than the Urella Fault. It seems that no Jurassic sediments occur to the east of this fault, which is believed to have been active in Jurassic times.

Exposures of the formation are sporadic, and are generally thin. Individual beds in the unit are markedly lenticular, and the differential compaction associated with this results in very variable dips.

No exposures of the Yarragadee Formation in the Geraldton area are more than 80 feet thick, and it is doubtful if more than 100 feet of the formation is present in this area. However a study of the Dongara, Yardarino, Mingenew, and Moora bores shows that the unit probably exceeds 4,000 feet in thickness in the deepest part of the Perth Basin, near the Darling Fault.

Fossils and age.—The only fossils known from the Yarragadee Formation are plants, but none have been recovered from exposures of the formation in the Geraldton area. However in the type area of the formation, 6½ miles north-north-west of Mingenew, there are numerous well-preserved fossil leaves in a white siltstone. Walkom (in McWhae *et al.* 1958) has reported the following forms from this locality: *Otozamites bengalensis, Otozamites feistmanteli, Otozamites bechei, Otozamites* cf. *bunburyanus, Araucarites cutchensis, Pagiophyllum* sp. *Brachyphyllum expansum, Elatoeladus plana,* and *Retinosporites indica*. Walkom considers that these fossils are of Middle or Upper Jurassic age. However Balme (1957, and written communication) has examined samples from the Mingenew bores and from a shaft only 2 miles north-west of the type locality, and he finds a probable Lower Cretaceous spore and pollen assemblage. These samples are in a similar stratigraphic position in the formation to Walkom's fossil leaves. Balme has also reported on the palynology of samples from the Yarragadee Formation in the Dongara, Yardarino, 47¼ mile-peg, and Moora bores. These suggest that the unit ranges from Middle Jurassic to Lower Cretaceous in age, with no evidence of a break within the unit.

Environment of deposition.—In the Geraldton area the Yarragadee Formation is believed to have been deposited under continental, fluviatile conditions, associated with movement along the Urella Fault. A continental environment of deposition is indicated by the rapidly alternating lithologies, the lenticular nature of individual beds, the lack of marine fossils and presence of plant fossils, and the variegated colouring of the unit.

Continental sedimentation is frequently associated with faulting, which results in continuing elevation of the source area. As the Yarragadee Formation is not known to occur east of the Urella Fault, it seems quite likely that this fault was active during Jurassic times. The Urella Fault dies out to the north, and in this area the Yarragadee Formation thins, and eventually disappears. The Urella Fault also dies out to the south, but there the Jurassic and later movement is taken up by the Darling Fault.

Structure

The Jurassic sediments of the Geraldton district are practically horizontal, showing only very small dips, measured in terms of a few feet per mile.

The base of the Newmarracarra Limestone is taken as a marker horizon, and in the area mapped in detail this is found to decrease in elevation from 660 feet above sea-level in the Bringo cutting to 539 feet at (690297). This is a fall to the south-west of just over 20 feet per mile, equivalent to a dip of only about 1/5°. This is the maximum regional dip found anywhere in the area, and is apparently due to differential compaction over the sloping Precambrian basement. In the Bringo cutting the limestone is only 14 feet above the Precambrian, whereas at (690297) there are about 220 feet of sediments beneath the limestone.

The major structural feature of the Geraldton area is the Geraldton Fault. It was named by Jutson (1914), and has also been referred to as the "Moonyoonooka Fault" (Woolnough and Somerville 1924). The evidence for the existence of the fault is based on geomorphology and the deep bores at Geraldton. The fault itself is not seen at the surface.

Geraldton is situated on a coastal plain which is backed by a dissected scarp of Jurassic sediments overlying the Precambrian basement. Jutson suggested that this is a retreated fault scarp. The scarp in itself is not sufficient evidence for the existence of a fault, but the hypothesis is confirmed by two deep bores in the Geraldton area—the Racecourse and Municipal bores. The Racecourse bore was drilled with calyx equipment in 1896-98, and was abandoned at a depth of 1,531 feet without reaching basement. Some of the cores were preserved from the bore, and these have been examined. The section in the bore is interpreted as: 0-53 feet, Quaternary; 53-400 feet, Jurassic; 400-1,531 feet, Lower Triassic or Upper Permian (Kockatea Shale). A few cores were retained from the Newmarracarra Limestone, which is believed to be present between 186 and 233 feet. As the Newmarracarra Limestone is flat-lying in its area of exposure (east of the bore) and the nearest exposure is about 540 feet above sea-level, the throw of the fault since the Jurassic can be expected to be of the order of 750 feet. However, the throw on the fault at the unconformity between the Kockatea Shale and the Precambrian, is believed to exceed 1,500 feet, based on the depth of this unconformity in the bore and its elevation at the surface. Hence it seems likely that there were two distinct periods of movement along the Geraldton Fault, the first during the Lower Triassic or late Permian, or between the Lower Triassic and the Jurassic, and the second after the Middle Jurassic.

The Geraldton Municipal bore struck granite at 1,435 feet. As the Racecourse bore was still in sediments at 1,531 feet, the unconformity must dip east, i.e. into the fault.

It is difficult to position the fault accurately owing to the lack of outcrop on the coastal plain. Hence the position of the fault shown on the map must be regarded as being only approximate.

In the Bringo cutting a series of small faults are exposed which fracture both the Precambrian and the overlying Jurassic sediments. They are normal faults, throwing down to the west, with the downthrown block usually dipping east (Plate 3, 1 and Plate 6). There are seven of these faults, the largest throw on any of them being only four feet, and the total throw about 14 feet. The faults tend to die out in the soft Jurassic sediments, sometimes passing into monoclines. These faults cannot be traced either on the ground or on air-photos, and are probably only local features. They may have formed when movement occurred along the main Geraldton Fault. Their age is evidently pre-laterite, for the contact between the hematite rock and the leached limestone (which are products of lateritization) is almost unaffected by the faulting.

One small pre-Jurassic fault was also noted in the cutting, displacing a vein in the Precambrian rocks.

Minor faulting has also been found in the Chapman Group sediments exposed in a cliff-face near "Ellendale" (895228). At this locality a west-dipping normal fault, having a throw of about five feet, is clearly visible.

At the eastern end of the Bringo cutting there is a small faulted anticline (Plate 3, 2). The faults are apparently due to tension at the crest of the anticline, and a small block of sediments has fallen between them. As there is no evidence of compressive movements elsewhere in the area, this anticline may well be due to folding over a tilted fault block at depth. Alternatively it may have formed by differential compaction over a buried ridge of Precambrian rocks.

At (724298) a series of well-developed landslides is visible. The sides of the hills around this locality are steep, and the hills are capped either by laterite or by Newmarracarra Limestone. The unconsolidated sandstones and shales of the Moonyoonooka Sandstone have failed, resulting in four main faulted blocks and many minor ones. They are classical examples of landslides, with the typical concave outline at the top of the hill, and a series of back-tilted blocks. The complex manner in which the Moonyoonooka Sandstone has been faulted during this landsliding can be seen in a nearby gully (723300) where the formation is well-exposed. The total throw of the landslides is about 170 feet.

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